2nd PALENC & 28th AIVC Conference, Crete, Sep 27-28, 2007

Global Cooling: Effect of Urban Albedo on Global Temperature

Hashem Akbari
Lawrence Berkeley National Laboratory, USA

Surabi Menon
Lawrence Berkeley National Laboratory, USA

Arthur Rosenfeld
California Energy Commission, USA

ABSTRACT

In many urban areas, pavements and roofs constitute over 60% of urban surfaces (roof 20-25%, pavements about 40%). The roof and the pavement albedo can be increased by about 0.25 and 0.10, respectively, resulting in a net albedo increase for urban areas of about 0.1.

Many studies have demonstrated building cooling-energy savings in excess of 20% upon raising roof reflectivity from an existing 10-20% to about 60%. We estimate U.S. potential savings in excess of $1 billion (B) per year in net annual energy bills. Increasing albedo of urban surfaces can reduce the summertime urban temperature and improve the urban air quality.

Increasing the urban albedo has the added benefit of reflecting more of the incoming global solar radiation and countering the effect of global warming. We estimate that increasing albedo of urban areas by 0.1 results in an increase of $3x10^{-4}$ in Earth albedo. Using a simple global model, the change in air temperature in lowest 1.8 km of the atmosphere is estimated at 0.01K.

Modelers predict a warming of about 3K in the next 60 years (0.05K/year). Change of 0.1 in urban albedo will result in 0.01K global cooling, a delay of ~0.2 years in global warming. This 0.2 years delay in global warming is equivalent to 10 Gt reduction in CO2 emissions.

1. INTRODUCTION

For more than two decades, the Heat Island Group (HIG) at Lawrence Berkeley National Laboratory (LBNL) has performed research to quantify the effect of increasing urban albedo on reducing cooling energy use, cooling urban areas, and improving urban air quality. In many urban areas, pavements and roofs constitute over 60% of urban surfaces (see Table 1; roof 20-25%, pavements about 40%) (Akbari et al., 2003, Rose et al., 2003, Akbari and Rose 2001a, Akbari and Rose 2001b).

Table 1: Urban fabric

Metropolitan Areas	Vegetation	Roofs	Pavements	Other
Salt Lake City	33.3	21.9	36.4	8.5
Sacramento	20.3	19.7	44.5	15.4
Chicago	26.7	24.8	37.1	11.4
Houston	37.1	21.3	29.2	12.4

Source: Rose et al., 2003

Many studies have demonstrated building cooling-energy savings in excess of 20% upon raising roof reflectivity from an existing 10-20% to about 60%. We estimate U.S. potential savings in excess of $1 billion (B) per year in net annual energy bills (cooling-energy savings minus heating-energy penalties). Increasing albedo of urban surfaces (roofs and pavements) can reduce the summertime urban temperature and improve the urban air quality (Taha 2002; Taha 2001; Taha et al. 2000; Rosenfeld et al. 1998; Akbari et al. 2001, Pomerantz et al. 1999). The energy and air quality savings resulting from increasing urban surface abedo in the U.S. can exceed $2B per year.

Increasing the urban albedo has the added benefit of reflecting more of the incoming global solar radiation and countering the effect of global warming (Kaarsberg and Akbari, 2006). Here we quantify the effect of increasing albedo of urban areas on the global temperature.

2. ESTIMATING GLOBAL URBAN AREAS

Figure 1 lists the area densities for the 100 largest metropolitan areas of the world (Wikipedia, 2006). The median area density is about 430 m^2 per urban dweller. The 100 largest metropolitan areas (with a total population of 670 M) comprise about 0.26% of the Earth land area. Assuming that about 3B people live in urban areas, total urban area of the globe is estimated at about 1.2% of land.

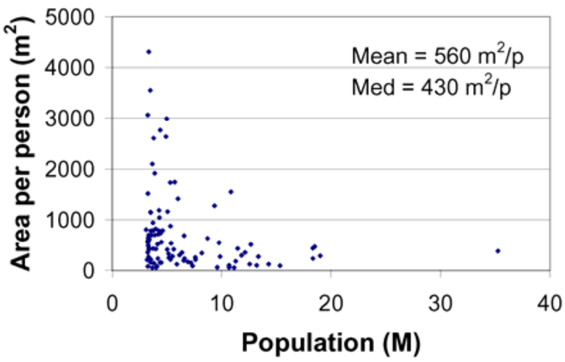


Figure 1: Area density for the 100 largest cities in the world. 670 million people live in these cities.

3. POTENTIALS FOR URBAN ALBEDO CHANGE

Rose et al. (2003) have estimated that the fractions of the roof and paved surface areas in four U.S. cities. The fraction of roof areas in these four cities varies from 20% for less dense cities to 25% for more dense cities. The fraction of paved surface areas varies between 29% to 44%. Many metropolitan urban areas around the world are less vegetated than typical U.S. cities. For this analysis, we consider an average area fraction of 25% and 40% for roof and paved surfaces, respectively.

Akbari and Konopacki (2005) have reviewed the solar reflectance of typical roofing materials used on residential and commercial buildings in many U.S. regions. A solar-reflective roof is typically light in color and absorbs less sunlight than a conventional dark-colored roof. Less absorbed sun light means a lower surface temperature, directly reducing heat gain from the roof and air-conditioning demand. Typical albedo values for low- and high-albedo roofs can be obtained from the cool roofing materials database (CRMD, 2007) developed at LBNL.

For the sloped-roof residential sector, available highly reflective materials are scarce. White asphalt shingles are available, but have a relatively low albedo of about 0.25. Although it can be argued that white coatings can be applied to shingles or tiles to obtain an aged albedo of about 0.5, this practice is not followed in the field. Some highly reflective white shingles are being developed, but are only in the prototype stage. Recently, one U.S. manufacturer has developed and marketing cool-colored fiberglass asphalt shingles with a solar reflectance of 0.25. Some reflective tiles and metal roofing products with greater than 50% reflectivity are also available.

Conversely, highly reflective materials for the low-slope commercial sector are on the market. White acrylic, elastomeric and cementatious coatings, as well as white thermoplastic membranes, can now be applied to built-up roofs to achieve an aged solar - reflectance of 0.6.

The albedo of typical standard roofing materials ranges from 0.10-0.25; one can conservatively assume that the average albedo of existing roofs does not exceed 0.20. The albedo of these surfaces can be increased to about 0.55 to 0.60.

Pomerantz et al. (2000a, 2000b, 1997) and Pomerantz and Akbari (1998) have documented the solar reflectance of many standard and reflective paved surfaces. They report that the solar reflectance of a freshly installed asphalt pavement is about 0.05. Aged asphalt pavements have a solar reflectance between 0.10-0.18, depending on the type of aggregate used in the asphalt mix. A light-color (low in carbon content) concrete can have an initial solar reflectance of 0.35-0.40 that will age to about 0.25-0.30. Pomerantz et al. also reviewed the solar reflectance of other paving materials such as chip seal, slurry coating, light-color coating.

Akbari et al. (2003) provide estimates for two scenarios for potential changes in the albedo of roofs and paved surfaces (See Table 2). Based on this data, we assume that roof albedo can increase by 0.25 for a net change of 0.25x0.25=0.06. The pavement albedo can increase by 0.10 for a net change of 0.40x0.10=0.04. Hence, the net potential change in albedo of urban area is estimated at 0.10.

Table 2: Two albedo modification scenarios

Surface-Type	Albedo Change		
	High	Low	This Study
Residential Roofs	0.3	0.1	0.25
Commercial Roofs	0.4	0.2	0.25
Pavements	0.25	0.15	0.10

Source: Akbari et al. (2003)

Increasing albedo of urban areas by 0.1 results in an increase of $3x10^{-4}$ in Earth albedo.

4. THE EFFECT OF CHANGING URBAN ALBEDOS ON GLOBAL TEMPERATURE

In his book, Harte (1998) presents a simplified method to estimate the effect of a change in the albedo on the globe on the Earth equilibrium temperature. Using Hart's simple global model, the change in air temperature in the lowest 1.8 km of the atmosphere is estimated at 0.01K. This estimate is corroborated by calculations of Hansen et al. (1997).

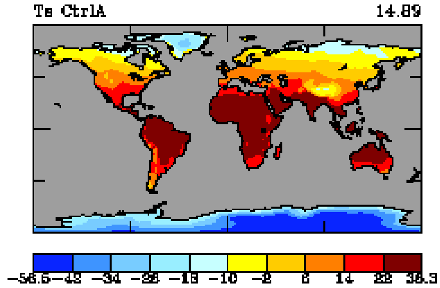
We have also carried out preliminary general circulation model (GCM) simulations to estimate the changes in the average globe temperature by changing the albedo of the all urban land surfaces. Currently, general circulation models (GCMs) are too coarse to estimate the effects of increased urban albedo. Most GCMs simulate the global climate with grid sizes larger than 2.5 degree (approximately 250 km; area of 62500 km^2). Most metropolitan urban areas are about 3000 – 5000 km^2 or about 1/100 of a typical GCM grid size. A change in the urban albedo of about 0.1, would reflect a change of 0.001 in the albedo of the grid. Such a small change in the albedo may not produce a significant feedback and hence the results of the GCM simulations may be questionable.

Several groups have performed general circulation model (GCM) simulations to investigate various aspects of global warming related to land-use changes (e.g Hansen et al. 1998, Bettes 2001, Levy et al. 2004, Chase et al. 2000, Jacobson, 2002, Oyama and Nobre 2004, to name a few). However, effects of urban albedos on climate have usually not been investigated. Some of the reasons are the coarse-grids of GCMs that are unable to resolve urban landscape features.

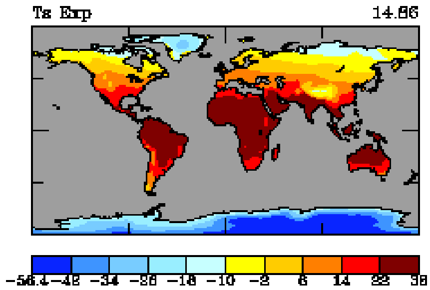
With current computational advances, it has become feasible to run a GCM at scales of 50 to 100 km with sub-grid adaptations of particular processes. Newer developments in land-surface schemes, based on satellite retrieved land-surface properties such as emissivity, are being incorporated in land-surface models that could be coupled to a GCM (Jin and Liang 2006; Jin and Shepherd 2005).

Our preliminary simulations using the NASA GISS GCM, that has a horizontal resolution of 4x5 degrees, predicts a decrease in global surface temperatures of about 0.03K (See figure 2.) These results were based on two sets of simulations: (1) A control run with prescribed present-day sea-surface temperatures called CtrlA; and (2) a simulation similar to CtrlA but with modified surface albedos, referred to as Exp. In simulation Exp, we assumed that the surface albedo of all urban land surfaces (2% of land surfaces) is purely reflective (set at 1) and the albedo of the rest of the land surfaces (98%) are not changed and are dependent on surface type, vegetation etc. as in the CtrlA version. The results from the two simulations, CtrlA and Exp, are averaged for three years after a spin-up of one year and are shown in Fig. 2. However, given the small changes we impose, and the coarse grid of the model, the signal to noise ratio is not strong and at best, the surface temperature changes given in Fig. 2 are preliminary values. We are investigating methods to more accurately estimate the effect of an albedo increase on global warming.

(a)



(b)



(c)

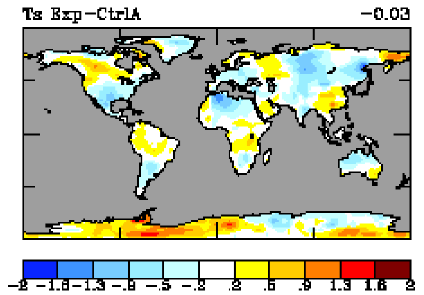


Figure 2. Preliminary simulations of surface temperature (Ts) using the NASA GISS GCM. Global annual averages are listed on r.h.s. of the figure.

4. GLOBAL COOLING: CO2 EQIVALENCY

Modellers predict a warming of about 3K in the next 60 years (0.05K/year). Change of 0.1 in urban albedo will result in 0.01K global cooling, a delay of ~0.2 years in global warming. The World's current rate of CO2 emissions is about 25 G tons/year (4.1 tons/year per person). The World's rate of CO2 emissions averaged over next 60 years is estimated at 50 G tons/year. Hence, the 0.2 years delay in global warming is worth 10 Gt CO2.

In Europe CO2 is currently traded at ~$10/ton. A 10 Gt CO2 reduction for changing albedo of roofs and paved surfaces is worth $100 billion. The contribution of cooler roofs to this CO2 savings is worth $60B.

5. CONCLUSIONS

Using cool roofs and cool pavements in urban areas, on the average, can increase the albedo of the urban areas by 0.1. An increase of 0.1 in urban albedo can cool the Earth by about 0.01K. This cooling can compensate for 0.2 years of the world's CO2 emissions; a saving of 10 Gt CO2, valued at $100B. Cool roofs also save air conditioning energy use at about $10B per year; $600B over the next 60 years.

Given these potential savings, we would like to recommend establishing an international organization where the developed countries offer $1 million per large city in a developing country, to trigger a cool roof/pavement program in that city.

6. ACKNOWLEDGEMENT

This work was supported by the California Energy Commission (CEC) through its Public Interest Energy Research Program (PIER), and by the Assistant Secretary for Energy Efficiency and Renewable Energy under Contract No. DE-AC02-05CH11231.

REFERENCES

Akbari, H., S. Konopacki. 2005. "Calculating energy-saving potentials of heat-island reduction strategies," *Energy Policy*, **33**: 721–756.

Akbari, H., L. S. Rose, and H. Taha. 2003. "Analyzing the land cover of an urban environment using high-resolution orthophotos," *Landscape and Urban Planning*, **63:** 1-14.

Akbari, H. and L.S. Rose. 2001a. "Characterizing the fabric of the urban environment: A case study of metropolitan Chicago, Illinois," Lawrence Berkeley National Laboratory Report LBL-49275, Berkeley, CA.

Akbari, H., and L. S. Rose. 2001b. "Characterizing the Fabric of the Urban Environment: A Case Study of Salt Lake City, Utah." Lawrence Berkeley National Laboratory Report No. LBNL-47851, Berkeley, CA.

Akbari, H., M. Pomerantz and H. Taha. 2001. "Cool Surfaces and Shade Trees to Reduce Energy Use and Improve Air Quality in Urban Areas," *Solar Energy* **70**(3); 295–310.

Betts, R., 2001. Biophysical impacts of land us eon present-day climate: near surface temperature and radiative forcing. Atmos. Sci. Lett. Dooi:10.1006/asle2000.0023.

Chase, T. N., R.A. Pielke Sr, T.G.F. Kittel, R.R. Nemani, and S.W. Running, 2000. Simulated impacts of historical land cover changes on global climate in northern winter. *Climate Dynam.* 16, 93-105.

CRMD. 2007. Cool Roof Material Database. http://eetd.lbl.gov/CoolRoofs/.

Harte, J. 1988. *Consider a Spherical Cow*, pages 166, 174, University Science Books, Berkeley, CA.

Hansen, J., M. Sato, A. Lacis, R. Ruedy, I. Tegen and E. Mathews, 1998. Climate forcings in the industrial era. Proc. Nat. Acad. Sci., 95, 12753-12758.

Hansen, J., M. Sato, R. Ruedy. 1997. "Radiative forcing and climate response," J Geophys Res, **102**, D6: 6831-6864.

Jacobson, M. Z., 2002. Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming, *J.*

Geophys. Res., 107, doi:10.1029/2001JD001376.

Jin, M. and J.M. Shepherd. 2005. Inclusion of urban landscape in a climate model, Bull. Amer. Meteorol. Soc.: 681-689.

Jin, M. and S. Liang, 2006: An improved land surface emissivity parameter for land surface models using global remote sensing observations. *J. Clim*., 19, 2867-2881.

Kaarsberg, T. and H. Akbari. 2006. "Cool roofs cool the plant," Home Energy, Sep/Oct issue: 38-41.

Levy, P.E., A.D. Friend, A. White, and M.G.R. Cannell, 2004: The influence of land use change on global-scale fluxes of carbon from terrestrial ecosystems. Clim. Change, 67: 185-209.

Oyama, M.D. and C.A. Nobre**,** 2004: Climatic Consequences of a Large-Scale Desertification in Northeast Brazil: A GCM Simulation Study. *J. Climate* 17, 3203-3213.

Rose, L. S, H. Akbari, and H. Taha. 2003. "Characterizing the Fabric of the Urban Environment: A Case Study of Greater Houston, Texas," Lawrence Berkeley National Laboratory Report LBNL-51448, Berkeley, CA.

Wikipedia, 2006. http://en.wikipedia.org/wiki/List_of_metropolitan_areas_by_population#endnote_USnone .

Pomerantz, M., H. Akbari, and J. T. Harvey. 2000a. "The benefits of cooler pavements on durability and visibility." Lawrence Berkeley National Laboratory Report No. LBNL-43443, Berkeley, CA.

Pomerantz, M., B. Pon, H. Akbari, and S. - C. Chang. 2000b. "The Effect of Pavement Temperatures on Air Temperatures in Large Cities." Lawrence Berkeley National Laboratory Report No. LBNL-43442, Berkeley, CA.

Pomerantz, M., H. Akbari, P. Berdahl, S. J. Konopacki and H. Taha. 1999. "Reflective surfaces for cooler buildings and cities," *Philosophical Magazine B* **79**(9);1457–1476.

Pomerantz, M., and H. Akbari. 1998 "Cooler Paving Materials for Heat Island Mitigation," *Proceedings of the 1998 ACEEE Summer Study on Energy Efficiency in Buildings* **9**;135.

Pomerantz, M., H. Akbari, A. Chen, H. Taha, and A. H. Rosenfeld. 1997. "Paving Materials for Heat Island Mitigation." Lawrence Berkeley National Laboratory Report No. LBL-38074, Berkeley, CA.

Rosenfeld, A. H., J. J. Romm, H. Akbari, and M. Pomerantz. 1998. "Cool Communities: Strategies for Heat Islands Mitigation and Smog Reduction," *Energy and Buildings*, **28**(1);51–62.

Taha, H. 2002. "Meteorological and Air Quality Impacts of Increased Urban Surface Albedo and Vegetative Cover in the Greater Toronto Area, Canada." Lawrence Berkeley National Laboratory Report No. LBNL-49210, Berkeley, CA.

Taha, H. 2001. "Potential Impacts of Climate Change on Tropospheric Ozone in California: A Preliminary Episodic Modeling Assessment of the Los Angeles Basin and the Sacramento Valley." Lawrence Berkeley National Laboratory Report No. LBNL-46695, Berkeley, CA.

Taha, H., S.-C. Chang and H. Akbari. 2000. "Meteorological and Air Quality Impacts of Heat Island Mitigation Measures in Three U.S. Cities." Lawrence Berkeley National Laboratory Report No. LBL-44222, Berkeley, CA.